8. Sound

Can you recall?

1. What type of wave is a sound wave?
2. Can sound travel in vacuum?
3. What are reverberation and echo?
4. What is meant by pitch of sound?

8.1 Introduction:

We are all aware of the ripples created on the surface of water when a stone is dropped in it. The water molecules oscillate up and down around their equilibrium positions but they do not move from one point to another along the surface of water. The disturbance created by dropping the stone, however travels outwards. This type of wave is a periodic and regular disturbance in a medium which does not cause any flow of material but causes the flow of energy and momentum from one point to another. There are different types of waves and not all types require material medium to travel through. We know that light is a type of wave and it can travel through vacuum. Here we will first study different types of waves, learn about their common properties and then study sound waves in particular.

Types of waves:

(i) **Mechanical waves:** A wave is said to be mechanical if a material medium is essential for its propagation. Examples of these types of waves are water waves, waves along a stretched string, seismic waves, sound waves, etc.

(ii) **EM waves:** These are generated due to periodic vibrations in electric and magnetic fields. These waves can propagate through material media, however, material medium is not essential for their propagation. These will be studied in Chapter 13.

(iii) **Matter waves:** There is always a wave associated with any object if it is in motion. Such waves are matter waves. These are studied in quantum mechanics.

Travelling or progressive waves are waves in which a disturbance created at one place travels to distant points and keeps travelling unless stopped by some external agencies. In such types of waves energy gets transferred from one point to another. Water waves mentioned above are travelling waves. They keep travelling outward from the point where stone was dropped until they are stopped by walls of the container or the boundary of the water body. Other type of waves are stationary waves about which we will learn in XIIth standard.

8.2 Common Properties of all Waves:

The properties described below are valid for all types of waves, however, here they are described for mechanical waves.

1) **Amplitude** (A): Amplitude of a wave motion is the largest displacement of a particle of the medium through which the wave is propagating, from its rest position. It is measured in metre in SI units.

2) **Wavelength** (λ): Wavelength is the distance between two successive particles which are in the same state of vibration. It is further explained below. It is measured in metre.

3) **Period** (T): Time required to complete one vibration by a particle of the medium is the period T of the wave. It is measured in seconds.

4) **Double periodicity:** Waves possess double periodicity. At every location the wave motion repeats itself at equal intervals of time, hence it is periodic in time. Similarly, at any given instant, the form of wave repeats at equal distances hence, it is periodic in space. In this way wave motion is a doubly periodic phenomenon i.e periodic in time and periodic in space.

5) **Frequency** (n): Frequency of a wave is the number of vibrations performed by a particle during each second. SI unit of frequency is hertz. (Hz) Frequency is a reciprocal of time period, i.e., $n = \dfrac{1}{T}$

6) Velocity (v): The distance covered by a wave per unit time is called the velocity of the wave. During the period (T), the wave covers a distance equal to the wavelength (λ) Therefore the magnitude of velocity of wave is given by,

$$\text{Magnitude of velocity} = \frac{\text{distance}}{\text{time}}$$

$$\text{v} = \frac{\text{wavelength}}{\text{period}}$$

$$\text{v} = \frac{\lambda}{T} \quad \text{--- (8.1)}$$

$$\text{but } \frac{1}{T} = n \text{ (frequency)} \quad \text{--- (8.2)}$$

$$\therefore \text{v} = n\lambda \quad \text{--- (8.3)}$$

This equation indicates that, the magnitude of velocity of a wave in a medium is constant. Increase in frequency of a wave causes decrease in its wavelength. When a wave goes from one medium to another medium, the frequency of the wave does not change. In such a case speed and wavelength of the wave change.

For mechanical waves to propagate through a medium, the medium should possess certain properties as given below:

i) The medium should be continuous and elastic so that the medium regains original state after removal of deforming forces.

ii) The medium should possess inertia. The medium must be capable of storing energy and of transferring it in the form of waves.

iii) The frictional resistance of the medium must be negligible so that the oscillations will not be damped.

7) **Phase and phase difference:**

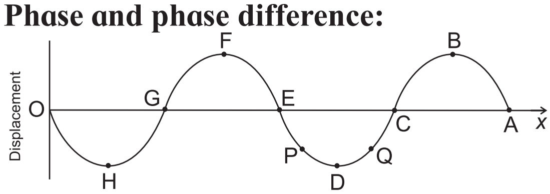


Fig. 8.1 (a): Displacement as a function of distance along the wave.

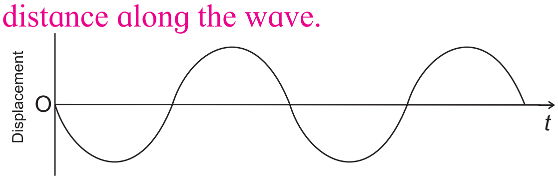


Fig. 8.1 (b): Displacement as a function of time.

In the Fig. 8.1 (a), displacements of various particles along a sinusoidal wave travelling along + ve x-axis are plotted against their respective distances from the source (at O) at a given instant. This plot is valid for transverse as well as longitudinal wave.

The state of oscillation of a particle is called its **phase.** In order to describe the phase at a place, we need to know (a) the displacement (b) the direction of velocity and (c) the oscillation number (during which oscillation) of the particle there.

In Fig. 8.1 (a), particles P and Q (or E and C or B and D) have same displacements but the directions of the their velocities are opposite. Particles B and F have same magnitude of displacements and same direction of velocity. Such particles are said to be in phase during their respective oscillations. Also, these are successive particles with this property of having same phase. Separation between these two particles is wavelength λ. These two successive particles differ by '1' in their oscillation number, i.e., if particle B is at its n^{th} oscillation, particle F will be at its $(n+1)^{th}$ oscillation as the wave is travelling along $+x$ direction. Most convenient way to understand phase is in terms of angle. For a sinusoidal wave, the variation in the displacement is a 'sine' function of distance from the source and of time as discussed below. For such waves it is possible for us to assign angles corresponding to the displacement (or time).

At the instant the above graph is drawn, the disturbance (energy) has just reached the particle A. The phase angle corresponding to this particle A can be taken as 0°. At this instant, particle B has completed quarter oscillation and reached its positive maximum ($\sin\theta = +1$). The phase angle θ of this particle B is $\pi^c/2 = 90°$ at this instant. Similarly, phase angles of particles C and E are π^c (180°) and $2\pi^c$ (360°) respectively. Particle F has completed one oscillation and is at its positive maximum during its second oscillation. Hence its phase angle is $2\pi^c + \dfrac{\pi^c}{2} = \dfrac{5\pi^c}{2}$.

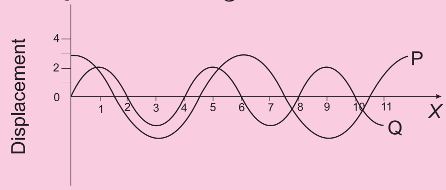
B and F are the successive particles in the same state (same displacement and same direction of velocity) during their respective oscillations. Separation between these two is wavelength (λ). Phase angle between these two differs by $2\pi^c$. Hence wavelength is better understood as the separation between two particles with phase difference of $2\pi^c$.

As noted above, waves possess double periodicity. This means the displacements of particles are periodic in space (as shown in Fig. 8.1 (a)) as well as periodic time. Figure 8.1 (b) shows the displacement of one particular particle as a function of time.

Activity :

(1) Using axes of displacement and distance, sketch two waves A and B such that A has twice the wavelength and half the amplitude of B.

(2) Determine the wavelength and amplitude of each of the two waves P and Q shown in figure below.



Characteristics of progressive wave

1) All vibrating particles of the medium have same amplitude, period and frequency.

2) State of oscillation i.e., phase changes from particle to particle.

Example 8.1: The speed of sound in air is 330 m/s and that in glass is 4500 m/s. What is the ratio of the wavelength of sound of a given frequency in the two media?

Solution: $v_{air} = n\,\lambda_{air}$

$v_{glass} = n\lambda_{glass}$

$$\therefore \frac{\lambda_{air}}{\lambda_{glass}} = \frac{v_{air}}{v_{glass}} = \frac{330}{4500} = 7.33\times10^{-2}$$

$$= 0.0733 \approx 7.33\times10^{-2}$$

8.3 Transverse Waves and Longitudinal Waves:

Progressive waves can be of two types, transverse and longitudinal waves.

Transverse waves : A wave in which particles of the medium vibrate in a direction perpendicular to the direction of propagation of wave is called transverse wave. Water waves are transverse waves, as water molecules vibrate perpendicular to the surface of water while the wave propagates along the surface.

Characteristics of transverse waves.

1) All particles of the medium in the path of the wave vibrate in a direction perpendicular to the direction of propagation of the wave with same period and amplitude.
2) When transverse wave passes through a medium, the medium is divided into alternate the crests i.e., regions of positive displacements and troughs i.e., regions of negative displacements.
3) A crest and an adjacent trough form one cycle of a transverse wave. The distance measured along the wave between any two consecutive points in the same phase (crest or trough) is called the wavelength of the wave.
4) Crests and troughs advance in the medium and are responsible for transfer of energy.
5) Transverse waves can travel through solids and on surfaces of liquids only. They can not travel through liquids and gases. EM waves are transverse waves but they do not require material medium for propagation.
6) When transverse waves advance through a medium there is no change in the pressure and density at any point of medium, however shape changes periodically.
7) If vibrations of all the particles along the path of a wave are constrained to be in a single plane, then the wave is called polarised wave. Transverse wave can be polarised.
8) Medium conveying a transverse wave must possess elasticity of shape.

Longitudinal waves : A wave in which particles of the medium vibrate in a direction parallel to the direction of propagation of wave is called longitudinal wave. Sound waves are longitudinal waves.

Characteristics of longitudinal waves:

1) All the particles of medium along the path of the wave vibrate in a direction parallel to the direction of propagation of wave with same period and amplitude.
2) When longitudinal wave passes through a medium, the medium is divided into regions of alternate compressions and rarefactions. Compression is the region where the particles of medium are crowded (high pressure zone), while rarefaction is the region where the particles of medium are more widely separated, i.e. the medium gets rarefied (low pressure zone).
3) A compression and adjacent rarefaction form one cycle of longitudinal wave. The distance measured along the wave between any two consecutive points having the same phase is the wavelength of wave.
4) For propagation of longitudinal waves, the medium should possess the property of elasticity of volume. Thus longitudinal waves can travel through solids. liquids and gases. Longitudinal wave can not travel through vacuum or free space.
5) The compression and rarefaction advance in the medium and are responsible for transfer of energy.
6) When longitudinal wave advances through a medium there are periodic variations in pressure and density along the path of wave and also with time.
7) Longitudinal waves can not be polarised, as the direction of vibration of particles and direction of propagation of wave are same or parallel.

8.4 Mathematical Expression of a Wave:

Let us describe a progressive wave mathematically. Since it is a progressive wave, we require a function of both the position x and time t. This function will describe the shape of the wave at any instant of time. Another requirement of the function is that it should describe the motion of the particle of the medium at that point. A sinusoidal progressive wave can be described by a sinusoidal function. Let us assume that the progressive wave is transverse and, therefore, the position of the particle of the medium is described by a fixed value of x. The displacement from the equilibrium position can be described by y. Such a sinusoidal wave can be written as follows:

$$y(x,t) = a \sin(kx - \omega t + \phi) \quad \text{--- (8.4)}$$

Hence a, k, ω and ϕ are constants.

Let us see the justification for writing this equation. At a particular instant say $t = t_0$,

$$y(x, t_0) = a \sin(kx - \omega t_0 + \phi)$$
$$= a \sin(kx + \text{constant})$$

Thus the shape of the wave at $t = t_0$, as a function of x is a sine wave.

Also, at a fixed location $x = x_0$,

$$y(x_0, t) = a \sin(kx_0 - \omega t + \phi)$$
$$= a \sin(\text{constant} - \omega t)$$

Hence the displacement y, at $x = x_0$ varies as a sine function.

This means that the particles of the medium, through which the wave travels, execute simple harmonic motion around their equilibrium position. In addition x must increase in the positive direction as time t increases, so as to keep $(kx - \omega t + \phi)$ a constant. Thus the Eq. (8.4) represents a wave travelling along the positive x axis. A wave represented by

$$y(x, t) = a \sin(kx + \omega t + \phi) \quad \text{--- (8.5)}$$

is a wave travelling in the direction of the negative x axis.

Symbols in Eq. (8.4):

y (x, t) is the displacement as a function of position (x) and time (t)

a is the amplitude of the wave.

ω is the angular frequency of the wave

k is the angular wave number

$(kx_0 - \omega t + \phi)$ is the argument of the sinusoidal wave and is the phase of the particle at x at time t.

8.5 The Speed of Travelling Waves

Speed of a mechanical wave depends upon the elastic properties and density of the medium. The same medium can support both transverse and longitudinal waves which have different speeds.

8.5.1 The speed of transverse waves

The speed of a wave is determined by the restoring force produced in the medium when it is disturbed. The speed also depends on inertial properties like mass density of the medium. The waves produced on a string are transverse waves. In this case the restoring force is provided by the tension T in the string. The inertial property i.e. the linear mass density m, can be determined from the mass of string M and its length L as $m = M/L$. The formula for speed of transverse wave on stretched string is given by

$$v = \sqrt{\frac{T}{m}} \qquad \text{--- (8.6)}$$

The derivation of the formula is beyond the scope of this book.

The important point here is that the speed of a transverse wave depends only on the properties of the string, T and m. It does not depend on wavelength or frequency of the wave.

8.5.2 The speed of longitudinal waves

In case of longitudinal waves, the particles of the medium oscillate forward and backward along the direction of wave propagation. This causes compression and rarefaction which travel in the medium as the medium possess elastic property.

Speed of sound in liquids and solids is higher than that in gases. The speed of sound as a longitudinal wave in an ideal gas is given by Newton's formula as discussed below.

Speed of sound in different media is given in table below.

Always remember:

When a sound wave goes from one medium to another its velocity changes along with its wavelength. Its frequency, which is decided by the source remains constant.

Table 8.1: Speed of Sound in Gas, Liquids, and Solids

Medium	Speed (m/s)
Gases	
Air [0°C]	331
Air [20°C]	343
Helium	965
Hydrogen	1284
Liquids	
Water (0°C)	1402
Water (20°C)	1482
Seawater	1522
Solids	
Vulcanised Rubber	54
Copper	3560
Steel	5941
Granite	6000
Aluminium	6420

8.5.3 Newton's formula for velocity of sound:

Propagation of longitudinal waves was studied by Newton. Sound waves travel through a medium in the form of compressions and rarefactions. The density of medium is greater at the compression while being smaller in the rarefaction. Hence the velocity of sound depends on elasticity and density of the medium. Newton formulated the relation as

$$v = \sqrt{\frac{E}{\rho}} \qquad \text{--- (8.7)}$$

where E is the proper modulus of elasticity of medium and ρ is the density of medium.

Newton assumed that, during propagation of sound, there is no change in the average temperature of the medium. Hence sound wave propagation in air is an isothermal process (temperature remaining constant) and isothermal elasticity should be considered. The volume elasticity of air determined under isothermal change is called isothermal bulk modulus and is equal to the atmospheric pressure 'P'. Hence Newtons formula for speed of sound in air is given by

$$v = \sqrt{\frac{P}{\rho}} \qquad \text{--- (8.8)}$$

As atmospheric pressure is given by P=hdg and at NTP,

h = 0.76 m of Hg

d = 13600 kg/m^3-density of mercury

ρ = 1.293 kg/m^3- density of air

and g = 9.8 m/s^2

$$v = \sqrt{\frac{0.76 \times 13600 \times 9.8}{1.293}}$$

v = 279.9 m/s at NTP.

This is the value of velocity of sound according to Newton's formula. But the experimental value of velocity of sound at 0^0C as determined earlier by a number of scientists is 332 m/s. The difference between predicted value by Newton's formula and experimental value is large and it is not due to experimental error. The Experimental value is 16% greater than the value given by the formula. Newton could not give satisfactory explanation of this discrepancy. It was resolved by French physicist Pierre Simon Laplace (1749-1827).

Example 8.2: Suppose you are listening to an out-door live concert sitting at a distance of 150 m from the speakers. Your friend is listening to the live broadcast of the concert in another country and the radio signal has to travel 3000 km to reach him. Who will hear the music first and what will be the time difference between the two? Velocity of light $=3\times10^8$ m/s and that of sound is 330m/s.

Solution: Time taken by sound to reach you

$$= \frac{150}{330} s = 0.4546$$

Time taken by the broadcasted sound (which is done by EM waves having velocity $=3\times10^8$m/s)

$$= \frac{3000 \text{ km}}{3\times10^5 \text{ km/s}} = \frac{3\times10^3}{3\times10^5} = 10^{-2}\,\text{s}$$

$\therefore$ your friend will hear the sound first. The time difference will be

= 0.4546 - 0.01

= 0.4446 s.

8.5.4 Laplace's correction

According to Laplace, the generation of compression and rarefaction is not a slow process but is a rapid process. If frequency is 256 Hz, the air is compressed and rarefied 256 times in a second. Such process must be a rapid process. Heat is produced during compression and is lost during rarefaction. This heat does not get sufficient time for dissipation. Due to this the total heat content remains the same. Such a process is called an adiabatic process and hence, adiabatic elasticity must be adiabatic and not isothermal elasticity, as was assumed by Newton.

Always remember:

In isothermal process temperature remains constant while in adiabatic process there is neither transfer of heat nor of mass.

The adiabatic modulus of elasticity of air is given by,

$$E = \gamma P \qquad \text{--- (8.9)}$$

where P is the pressure of the medium (air) and γ is ratio of specific heat of air at constant pressure (C_p) to the specific heat of air at constant volume (C_v) called as the adiabatic ratio

$$\text{i.e., } \gamma = \frac{C_p}{C_v} \qquad \text{--- (8.10)}$$

For air the ratio of C_p / C_v is 1.41

i.e. $\gamma = 1.41$

Newton's formula for speed of sound in air as modified by Laplace to give

$$v = \sqrt{\frac{\gamma P}{\rho}} \qquad \text{--- (8.11)}$$

Accoriding to this formula velocity of sound at NTP is

$$v = \sqrt{\frac{1.41 \times 0.76 \times 13600 \times 9.8}{1.293}}$$

= 332.3 m/s

This value is in close agreement with the experimental value. As seen above, the velocity of sound depends on the properties of the medium.

8.5.5 Factors affecting speed of sound:

As sound waves travel through atmosphere (open air), some factors related to air affect the speed of sound.

Do you know ?

C_p, the specific heat of gas at constant pressure, is defined as the quantity of heat required to raise the temperature of unit mass of gas through 1^0 K when pressure remains constant.

C_v, the specific heat of gas at constant volume, is defined as the quantity of heat required to raise the temperature of unit mass of gas through 1^0 K when volume remains constant.

When pressure is kept constant the volume of the gas increases with increase in temperature. Thus additional heat is required to increase the volume of gas against the external pressure. Therefore heat required to raise the temperature of unit mass of gas through 1^0 K when pressure is kept constant is greater than the heat required when volume is kept constant. i.e. $C_p > C_v$.

a) Effect of pressure on velocity of sound

According to Laplace's formula velocity of sound in air is

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

If M is the mass and V is volume of air then

$$\rho = \frac{M}{V}$$

$$\therefore v = \sqrt{\frac{\gamma P V}{M}} \qquad \text{--- (8.12)}$$

At constant temperature PV = constant according to Boyle's law. Also M and γ are constant, hence v = constant.

Therefore at constant temperature, a change in pressure has no effect on velocity of sound in air. This can be seen in another way. For gaseous medium, $PV = nRT$, n being the number of moles.

$$\therefore v = \sqrt{\frac{\gamma n R T}{M}} \qquad \text{--- (8.13)}$$

Hence for gaseous medium obeying ideal gas equation change in pressure has no effect on velocity of sound unless there is change in temperature.

Example 8.3: Consider a closed box of rigid walls so that the density of the air inside it is constant. On heating, the pressure of this enclosed air is increased from P_0 to P. It is now observed that sound travels 1.5 times faster than at pressure P_0 calculate P/P_0.

Solution:

$$v_P = \sqrt{\frac{\gamma P_o}{\rho}}$$

$$v_{Po} = \sqrt{\frac{\gamma P_o}{\rho}}$$

$$v_P = 1.5\, v_{Po}$$

$$\sqrt{\frac{\gamma P}{\rho}} = 1.5\sqrt{\frac{\gamma P_o}{\rho}}$$

$$\frac{P}{\rho} = 2.25\frac{P_o}{\rho}$$

$$P = 2.25\, P_o$$

(b) Effect of temperature on speed of sound

Suppose v_o and v are the speeds of sound at T_0 and T in kelvin respectively. Let ρ_0 and ρ be the densities of gas at these two temperatures. The velocity of sound at temperature T_0 and T can be written by using Eq. (8.13),

$$v_0 = \sqrt{\frac{\gamma R T_0}{M}} \quad \text{--- } M \text{ is molar mass, n = 1}$$

$$v = \sqrt{\frac{\gamma R T}{M}}$$

$$\therefore \frac{v}{v_0} = \sqrt{\frac{RT}{RT_0}}$$

$$\therefore \frac{v}{v_0} = \sqrt{\frac{T}{T_0}} \qquad \text{--- (8.14)}$$

This equation shows that speed of sound in air is directly proportional to the square root of absolute temperature. Thus, speed of sound in air increases with increase in temperature. Taking T_o= 273 K and writing T= (273 + t) K where t is the temperature in degree celsius. The ratio of velocity of sound in air at t ^{0}C to that at 0^0C is given by,

$$\therefore \frac{v}{v_0} = \sqrt{\frac{273+t}{273}}$$

$$\therefore \frac{v}{v_0} = \sqrt{1+\frac{t}{273}}$$

$$\therefore \frac{v}{v_0} = \sqrt{1+\alpha t} \quad \text{where } \alpha = \frac{1}{273}$$

or, $v = v_0 (1+\alpha t)^{\frac{1}{2}}$

As α is very small,we can write

$$v \simeq v_0 \left(1+\frac{1}{2}\alpha t\right)$$

$$v = v_0 \left(1+\frac{1}{2}\times\frac{1}{273}t\right)$$

$$v = v_0 \left(1+\frac{t}{546}\right)$$

$$v = v_0 + \frac{v_0}{546}t$$

But v_0 =332 m/s at 0^0C

$$\therefore v = v_0 + \frac{332}{546}t$$

$$\therefore v \simeq v_0 + (0.61)t, \qquad \text{--- (8.15)}$$

i.e., for 1°C rise in temperature velocity increases by 0.61 m/s. Hence for small variations in temperature (< 50° C), the speed of sound changes linearly with temperature.

(c) Effect of humidity on speed of sound

Humidity (moisture) in air depends upon the presence of water vapour in it. Let ρ_m and ρ_d be the densities of moist and dry air respectively. If v_m and v_d are the speeds of sound in moist air and dry air then using Eq. (8.11).

$$v_m = \sqrt{\frac{\gamma P}{\rho_m}}$$

$$\text{and } v_d = \sqrt{\frac{\gamma P}{\rho_d}}$$

$$\therefore \frac{v_m}{v_d} = \sqrt{\frac{\rho_d}{\rho_m}} \qquad \text{--- (8.16)}$$

Moist air is always less dense than dry air, i.e.,

$\rho_m < \rho_d$

(ρ_m = 0.81 kg/m³(at 0°C) and

ρ_d = 1.29 kg/m³(at 0°C))

$\therefore v_m > v_d$.

Thus, the speed of sound in moist air is greater than speed of sound in dry air. i.e speed increases with increase in the moistness of air.

8.6 Principle of Superposition of Waves:

Waves don't display any repulsion towards each other. Therefore two wave patterns can overlap in the same region of the space without affecting each other. When two waves overlap their displacements add vectorially. This additive rule is referred to as the principle of superposition of waves.

When two or more waves travelling through a medium arrive at a point of medium simultaneously, each wave produces its own displacement at that point independent of the others. Hence the resultant displacement at that point is equal to the vector sum of the displacements due to all the waves. The phenomenon of superposition will be discussed in detail in XIIth standard.

8.7 Echo, reverberation and acoustics:

Sound waves obey the same laws of reflection as those of light.

8.7.1 Echo:

An echo is the repetition of the original sound because of reflection from some rigid surface at a distance from the source of sound. If we shout in a hilly region, we are likely to hear echo.

Why can't we hear an echo at every place? At 22^0C, the velocity of sound in air is 344 m/s. Our brain retains sound for 0.1 second. Thus for us to hear a distinct echo, the sound should take more than 0.1s after starting from the source (i.e., from us) to get reflected and come back to us.

distance = speed × time

= 344 × 0.1

= 34.4 m.

To be able to hear a distinct echo, the reflecting surface should be at a minimum distance of half of the above distance i.e 17.2 m. As velocity depends on the temperature of air, this distance will change with temperature.

Example 8.4: A man shouts loudly close to a high wall. He hears an echo. If the man is at 40 m from the wall, how long after the shout will the echo be heard ? (speed of sound in air = 330 m/s)

solution: The distance travelled by the sound wave

$= 2 \times$ distance from man to wall.

$= 2 \times 40$

$= 80$ m.

$$\therefore \text{Time taken to travel the distance} = \frac{\text{distance}}{\text{speed}}$$

$$= \frac{80\ \text{m}}{330\ \text{m/s}}$$

$$= 0.24\ \text{s}$$

$\therefore$ The man will hear the echo 0.24 s after he shouts.

8.7.2 Reverberation:

If the reflecting surface is nearer than 15 m from the source of sound, the echo joins up with the original sound which then seems to be prolonged. Sound waves get reflected multiple times from the walls and roof of a closed room which are nearer than 15 m. This causes a single sound to be heard not just once but continuously. This is called reverberation. It is this the persistence of sound after the source has switched off, as a result of repeated reflection from walls, ceilings and other surfaces. Reverberation characteristics are important in the design of concert halls, theatres etc.

If the time between successive reflections of a particular sound wave reaching us is small, the reflected sound gets mixed up and produces a continuous sound of increased loudness which can't be heard clearly.

Reverberation can be decreased by making the walls and roofs rough and by using curtains in the hall to avoid reflection of sound. Chairs and wall surfaces are covered with sound absorbing materials. Porous cardboard sheets, perforated acoustic tiles, gypsum boards, thick curtains etc. at the ceilings and at the walls are most convenient to reduce reverberation.

8.7.3 Acoustics:

The branch of physics which deals with the study of production, transmission and reception of sound is called acoustics. This is useful during the construction of theaters and auditorium. While designing an auditorium, proper care for the absorption and reflection of sound should be taken. Otherwise audience will not be able to hear the sound clearly.

For proper acoustics in an auditorium the following conditions must be satisfied.

1) The sound should be heard sufficiently loudly at all the points in the auditorium. The surface behind the speaker should be parabolic with the speaker at its focus; so that the distribution of sound is uniform in the auditorium. Reflection of sound is helpful in maintaining good loudness through the entire auditorium.
2) Echoes and reverberation must be eliminated or reduced. Echoes can be reduced by making the reflecting surfaces more absorptive. Echo will be less if the auditorium is full.
3) Unnecessary focusing of sound should be avoided and there should not be any zone of poor audibility or region of silence. For that purpose curved surface of the wall or ceiling should be avoided.
4) Echelon effect : It is due to the mixing of sound produced in the hall by the echoes of sound produced in front of regular structure like the stairs. To avoid this, stair type construction must be avoided in the hall.
5) The auditorium should be sound-proof when closed, so that stray sound can not enter from outside.
6) For proper acoustics no sound should be produced from the inside fittings, seats, etc. Instead of fans, air conditioners may be used. Soft action door closers should be used.

Acoustics observed in nature

The importance of acoustic principles goes far beyond human hearing. Several animals use sound for navigation.

(a) Bats depends on sound rather than light to locate objects. So they can fly in total darkness of caves. They emit short ultrasonic pulses of frequency 30 kHz to 150 kHz. The resulting echoes give them information about location of the obstacle.

(b) Dolphins use an analogous system for underwater navigation. The frequencies are subsonic about 100 Hz. They can sense an object of about the size of a wavelength i.e., 1.4 m or larger.

Medical applications of acoustics

(a) Shock waves which are high pressure high amplitude waves are used to split kidney stones into smaller pieces without invasive surgery. A shock wave is produced outside the body and is then focused by a reflector or acoustic lens so that as much of its energy as possible converges on the stone. When the resulting stresses in the stone exceeds its tensile strength, it breaks into small pieces which can be removed easily.

(b) Reflection of ultrasonic waves from regions in the interior of body is used for ultrasonic imaging. It is used for prenatal (before the birth) examination, detection of anamolous conditions like tumour etc and the study of heart valve action.

(c) At very high power level, ultrasound is selective destroyer of pathalogical tissues in treatment of arthritis and certain type of cancer.

Other applications of acoustics

(a) SONAR is an acronym for Sound Navigational Ranging. This is a technique for locating objects underwater by transmitting a pulse of ultrasonic sound and detecting the reflected pulse. The time delay between transmission of a pulse and the reception of reflected pulse indicates the depth of the object. This system is useful to measure motion and position of the submerged objects like submarine.

(b) Acoustic principle has important application to environmental problems like noise control. The design of quiet-mass transit vehicle involves the study of generation and propagation of sound in the motor's wheels and supporting structures.

(c) We can study properties of the Earth by measuring the reflected and refracted elastic waves passing through its interior. It is useful for geological studies to detect local anomalies like oil deposits etc.

8.8 Qualities of sound:

Audible sound or human response to sound:

Whenever we talk about *audible* sound, what matters is how *we perceive* it. This is purely a subjective attribute of sound waves.

Major qualities of sound that are of our interest are (i) Pitch, (ii) Timbre or quality and (iii) Loudness.

(i) Pitch:

This aspect refers to sharpness or shrillness of the sound. If the frequency of sound is increased, what we perceive is the increase in the pitch or we feel the sound to be sharper. *Tone* refers to the single frequency of that wave while a note may contain one or more than one tones. We use the words high pitch or high tones if frequency is higher. As sharpness is a subjective term, sentences like "sound of double frequency is doubly sharp" make no sense. Also, a high pitch sound *need not* be louder. Tones of guitar are sharper than that of a base guitar, sound of tabla is sharper than that of a dagga, (in general) female sound is sharper than that of a male sound and so on.

For a sound amplifier (or equaliser) when we raise the *treble* knob (or *treble* Button), high frequencies are boosted and if we raise *bass* knob, low frequencies are boosted.

(ii) Timbre (sound quality)

During telephonic conversation with a friend, (mostly) you are able to know who is speaking at the other end even if you are not told about who is speaking. Quite often we say, "Couldn't you recognise the voice?" The sound quality in this context is called *timbre*. Same song played on a guitar, a violin, a harmonium or a piano feel significantly different and we can easily identify that instrument. Quality of sound of any sound instrument (including our vocal organ) depends upon the mixture of tones and overtones in the sound generated by that instrument. Even our own sound quality during morning (after we get up) and in the evening is different. It is drastically affected if we are suffering from *cold* or *cough*. Concept of overtones will be discussed during XIIth standard.

(iii) Loudness:

Intensity of a wave is a measurable quantity which is proportional to square of the amplitude ($I \propto A^2$) and is measured in the (SI) unit of W/m^2. Human perception of intensity of sound is *loudness*. Obviously, if intensity is more, loudness is more. The human response to intensity is not linear, i.e., a sound of double intensity is louder but not doubly loud. This is also valid for brightness of light. In both cases, the response is approximately logarithmic. Using this property, the loudness (and brightness) can be measured.

Under ideal conditions, for a perfectly healthy human ear, the least audible intensity is $I_0 = 10^{-12}$ W/m^2. Loudness of a sound of intensity I, measured in the unit ***bel*** is given by

$$L_{\text{bel}} = log_{10}\left(\frac{I}{I_0}\right) \quad \text{--- (8.17)}$$

Popular or commonly used unit for loudness is *deci*bel. We know, 1 *deci*metre or 1 dm = 0.1m. Similarly, 1 decibel or 1 db = 0.1 bel. $\therefore$ 1 bel = 10 db. Thus, loudness expressed in db is 10 times the loudness in bel

$$\therefore L_{\text{db}} = 10\, L_{bel} = 10\, log_{10}\left(\frac{I}{I_0}\right)$$

For sound of least audible intensity I_0,

$$L_{db} = 10\, log_{10}\left(\frac{I_0}{I_0}\right) = 10\, log_{10}(1) = 0 \quad \text{--- (8.18)}$$

This corresponds to threshold of hearing

For sound of 10 db,

$$10 = 10\, log_{10}\left(\frac{I}{I_0}\right) \therefore \left(\frac{I}{I_0}\right) = 10^1 \text{or } I = 10\, I_0$$

For sound of 20 db,

$$20 = 10\, log_{10}\left(\frac{I}{I_0}\right) \therefore \left(\frac{I}{I_0}\right) = 10^2 \text{or } I = 100\, I_0$$

and so on.

Hence, loudness of 20 db sound is *felt* double that of 10 db, but its intensity is 10 times that of the 10 db sound. Now, we feel 40 db sound twice as loud as 20 db sound but its intensity is 100 times as that of 20 db sound and 10000 times that of 10 db sound. This is the power of logarithmic or exponential scale.

If we move away from a (practically) point source, the intensity of its sound varies inversely with square of the distance, i.e., $I \propto \frac{1}{r^2}$.

Whenever you are using earphones or jam your mobile at your ear, the distance from the source is too small. Obviously, such a habit for a long time can affect your normal hearing.

Example 8.5: When heard independently, two sound waves produce sensations of 60 db and 55 db respectively. How much will the sensation be if those are sounded together, perfectly in phase?

Solution:

$$L_1 = 60\, db = 10\, log_{10}\frac{I_1}{I_0} \therefore \frac{I_1}{I_0} = 10^6 \text{ or } I_1 = 10^6\, I_0$$

Similarly, $I_2 = 10^{5.5}\, I_0$

As the waves combine perfectly in phase, the vector addition of their amplitudes will be given by $A^2 = (A_1 + A_2)^2 = A_1^2 + A_2^2 + 2A_1A_2$

As intensity is proportional to square of the amplitude.

$$\therefore I = I_1 + I_2 + 2\sqrt{I_1 I_2}$$

$$= 10^5\, I_0\left(10^1 + 10^{0.5} + 2\sqrt{10^{1.5}}\right)$$

$$= 10^5\, I_0\left(10 + 3.1623 + 2\times 10^{0.75}\right)$$

$$= 24.41\times 10^5\, I_0 = 2.441\times 10^6\, I_0$$

$$\therefore L = 10\, log_{10}\left(\frac{I}{I_0}\right) = 10\, log_{10}\left(2.441\times 10^6\right)$$

$$= 10\left[log_{10}(2.441) + log_{10}\left(10^6\right)\right]$$

$$+10(0.3876 = 6)$$

$$= 63.876\,\text{db} \approx 64\text{ db}$$

It is interesting to note that there is only a marginal increase in the loudness.

Table 8.2: Approximate Decibel Ratings of Some Audible Sounds

Source or description of noise	Loudness, L_{db}	Effcet
Extremely loud	160	Immediate ear damage
Jet aeroplane, near 25 m	150	Rupture of eardrum
Auto horn, one metre, Aircraft take off, 60 m	110	Strongly painful
Diesel train, 30 m, Average factory	80	
Highway traffic, 8 m	70	Uncomfortable
Conversion at a restaurant	60	
Conversation at home	50	
Quiet urban background sound	40	
Quiet rural area	30	Virtual silence
Whispering of leaves, 5 m	20	
Normal breathing	10	
Threshold of hearing	0	

8.9 Doppler Effect:

Have you ever heard an approaching train and noticed distinct change in the pitch of the sound of its whistle, when it passes away ? Same thing similar happens when a listener moves towards or away from the stationary source of sound. Such a phenomenon was first identified in 1842 by Austrian physicist Christian Doppler (1803-1853) and is known as Doppler effect.

When a source of sound and a listener are in motion relative to each other the frequency of sound heard by listener is not the same as the frequency emitted by the source.

Doppler effect is the apparent change in frequency of sound due to relative motion between the source and listener. Doppler effect is a wave phenomenon. It holds for sound waves and also for EM waves. But here we shall consider it for sound waves only.

The changes is frequency can be studied under 3 different conditions:

1) When listener is stationary but source is moving.
2) When listener is moving but source is stationary.
3) When listener and source both are moving.

Do you know ?

According to the world health organisation a billion young people could be at risk of hearing loss due to unsafe listening practices. Among teenagers and young adults aged 12-35 years (i) about 50% are exposed to unsafe levels of sound from use of personal audio devices and (ii) about 40% are exposed to potentially damaging sound levels at clubs, discotheques and bars.

8.9.1 Source Moving and Listener Stationary:

Consider a source of sound S, moving away from a stationary listener L (called relative recede) with velocity v_s. Speed of sound waves with respect to the medium is v which is always positive. Suppose the listener uses a detector for counting each wave crest that reaches it.

Initially (at $t = 0$), source which is at point S_1 emits a crest when at distance d from the listener see Fig. 8.2 (a). This crest reaches the listener at time $t_1 = d/v$. Let T_0 be the time period at which the waves are emitted. Thus, at $t = T_0$ the source moves the distance $= v_s T_o$ and reaches the point S_2. Distance of S_2 from the listener is $(d + v_s T_o)$. when at S_2, the source emits second crest. This crest reaches the listener at

$$t_2 = T_0 + \left[\frac{d + v_s T_0}{v}\right] \quad \text{--- (8.19)}$$

Similarly at time pT_o, the source emits its $(p+1)^{th}$ crest (where, p is an integer, p = 1,2,3,...). It reaches the listener at time

$$t_{p+1} = pT_0 + \left[\frac{d + p\text{v}_s T_0}{\text{v}}\right]$$

Hence the listener's detector counts p crests in the time interval

$$t_{p+1} - t_1 = pT_0 + \left[\frac{d + p\text{v}_s T_0}{\text{v}}\right] - \frac{d}{\text{v}}$$

Hence the period of wave as recorded by the listener is

$$T = \frac{(t_{p+1} - t_1)}{p} \qquad \text{or}$$

$$T = \frac{\left[pT_0 + \frac{d + p\text{v}_s T_0}{\text{v}} - \frac{d}{\text{v}}\right]}{p}$$

$$T = T_0 + \frac{\text{v}_s T_0}{\text{v}}$$

$$T = T_0\left[1 + \frac{\text{v}_s}{\text{v}}\right]$$

$$T = T_0\left[\frac{\text{v} + \text{v}_s}{\text{v}}\right]$$

$$\therefore \frac{1}{T} = \frac{1}{T_0}\left[\frac{\text{v}}{\text{v} + \text{v}_s}\right]$$

$$\therefore n = n_0\left[\frac{\text{v}}{\text{v} + \text{v}_s}\right] \qquad \text{--- (8.20)}$$

where n is the frequency recorded by the listener and n_o is the frequency emitted by the source.

If source of sound is moving towards the listener with speed v_s (called relative approach), the second term from Eq. (8.18) onwards, will be negative (or will be subtracted).

Thus, in this case,

$$n = n_0\left[\frac{\text{v}}{\text{v} - \text{v}_s}\right] \qquad \text{--- (8.21)}$$

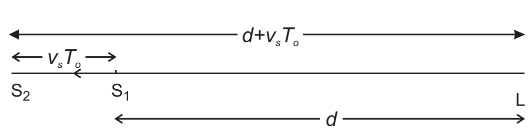


Fig. 8.2 (a): Doppler effect detected when the source is moving and listener is at rest in the medium.

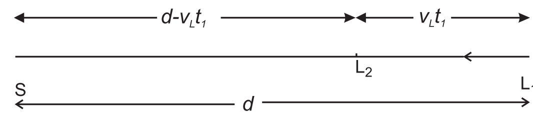


Fig. 8.2 (b): Doppler effect detected when the listener is moving and source is at rest in the medium.

8.9.2 Listener Approaching a Stationary Source with Velocity v_L:

Consider a listener approaching with velocity v_L towards a stationary source S as shown in Fig. 8.2 (b). Let the first wave be emitted by the source at $t = 0$, when the listener was at L_1 at an initial distance d from the source. Let t_1 be the instant when the listener receives this (wave), his position being L_2. During time t_1, the listener travels distance $\text{v}_L t_1$ towards the stationary source. In this time, the sound wave travels distance $\left(d - \text{v}_L t_1\right)$ with speed v.

$$\therefore t_1 = \frac{d - \text{v}_L t_1}{\text{v}} \qquad \therefore t_1 = \frac{d}{\text{v} + \text{v}_L}$$

Second wave is emitted by the source at $t = T_0$ = the time period of the waves emitted by the source. Let t_2 be the instant when the listener receives second wave. During time t_2, the distance travelled by the listener is $\text{v}_L t_2$. Thus, the distance to be travelled by the sound to reach the listener is then $d - \text{v}_L t_2$.

$\therefore$ Sound (second wave) travels this distance with speed v in time $= \dfrac{d - \text{v}_L t_2}{\text{v}}$

However, this time should be counted after T_0, as the second wave was emitted at $t = T_0$.

$$\therefore t_2 = T_0 + \frac{d - \text{v}_L t_2}{\text{v}} \qquad \therefore t_2 = \frac{\text{v}T_0 + d}{\text{v} + \text{v}_L}$$

Similarly, $t_3 = 2T_0 + \dfrac{d - \text{v}_L t_3}{\text{v}} \qquad \therefore t_3 = \dfrac{2\text{v}T_0 + d}{\text{v} + \text{v}_L}$

Extending this argument to $(p+1)^{th}$ wave, we can write,

$$t_{p+1} = pT_0 + \frac{d - \text{v}_L t_{p+1}}{\text{v}} \qquad \therefore t_{p+1} = \frac{p\text{v}T_0 + d}{\text{v} + \text{v}_L}$$

Time duration between instances of receiving successive waves is the *observed* or *recorded* period T.

$$\therefore pT = t_{p+1} - t_1 = \frac{pvT_0 + d}{v + v_L} - \frac{d}{v + v_L} = \frac{pvT_0}{v + v_L}$$

$$\therefore T = T_0\left(\frac{v}{v + v_L}\right) \qquad \text{--- (8.22)}$$

$$\therefore \frac{1}{T} = \frac{1}{T_0}\left(\frac{v + v_L}{v}\right)$$

$$\therefore n = n_0\left(\frac{v + v_L}{v}\right) \qquad \text{--- (8.23)}$$

8.9.3 Both Source and Listener are Moving:

In general when both the source and listener are in motion, we can write the observed frequency

$$n = n_0\left[\frac{v \pm v_L}{v \mp v_s}\right] \qquad \text{--- (8.24)}$$

Where the upper signs (in both numerator and denominator) should be chosen during relative approach while lower signs should be chosen during relative recede. It must be remembered that 'when you are deciding the sign for any one of these, the other should be considered to be at rest'.

Illustration:

Consider an observer or listener and a source moving with respective velocities v_L and v_S along the same direction. In this case, listener is approaching the source with v_L (irrespective of whether source is moving or not). Thus, the upper, i.e., positive sign, should be chosen for numerator. However, the source is moving with v_S away form the listener irrespective of listener's motion. Thus the lower sign in the denominator which is positive has to be chosen.

$$\therefore n = n_o\left[\frac{v + v_L}{v + v_s}\right] \qquad \text{--- (8.25)}$$

Case (I) If $|v_L| = |v_s|$, $n = n_o$. Thus there is no Doppler shift as there is no relative motion, even if both are moving.

Case (II) If $|v_L| > |v_s|$, numerator will be greater, $n > n_o$. This is because there is relative approach as the listener approaches the source faster and the source is receding at a slower rate.

Case (III) If $|v_L| < |v_s|$, $n < n_o$ as now there is relative recede (source recedes faster, listener approaches slowly).

8.9.4 Common Properties between Doppler Effect of Sound and Light:

A) Wherever there is relative motion between listener (or observer) and source (of sound or light waves), the recorded frequency is different than the emitted frequency.

B) Recorded frequency is higher (than emitted frequency), if there is relative approach.

C) Recorded frequency is lower, if there is relative recede.

D) If v_L or v_s are much smaller then wave speed (speed of sound or light) we can use v_r as relative velocity. In this case, using Eq. (8.24)

$$\frac{\Delta n}{n} \simeq \frac{v_r}{v} \simeq \frac{\Delta\lambda}{\lambda} \qquad \text{--- (8.26)}$$

where Δn is Doppler shift or change in the recorded frequency, i.e., $|n - n_o|$ and $\Delta\lambda$ is the recorded change in wavelength.

$$\therefore \frac{|n - n_0|}{n} \simeq \frac{v_r}{v}$$

$$\therefore n = n_0\left(1 \pm \frac{v_r}{v}\right) \qquad \text{--- (8.27)}$$

Once again upper sign is to be used during relative approach while lower sign is to be used during relative recede.

E) If velocities of source and observer (listener) are not along the same line their respective components along the line joining them should be chosen for longitudinal Doppler effect and the same mathematical treatment is applicable.

8.9.5 Major Differences between Doppler Effects of Sound and Light:

A) As the speed of light is absolute, only relative velocity between the observer and the source matters, i.e., who is in motion is not relevant.

B) Classical and relativistic Doppler effects are different in the case of light, while in case of sound, it is only classical.

C) For obtaining exact Doppler shift for sound waves, it is absolutely important to know who is in motion.

D) If wind is present, its velocity alters the speed of sound and hence affects the Doppler shift. In this case, component of the wind velocity (v_w) is chosen along the line joining source and observer. This is to be algebraically added with the velocity of sound. Hence 'v' is to be replaced by ($v \pm v_w$) in all the above expressions. Positive sign to be used if v and v_w are along the same direction (remember that v is always positive and always from source to listener). Negative sign is to be used if v and v_w are oppositely directed.

Example 8.6: A rocket is moving at a speed of 220 m/s towards a stationary target. It emits a wave of frequency 1200 Hz. Some of the sound reaching the target gets reflected back to the rocket as an echo. Calculate (1) The frequency of sound detected by the target and (2) The frequency of echo detected by rocket (velocity of sound= 330 m/s.)

Solution: Given, target stationary, i.e.,

$v_L = 0$, $v_s = 220$ m/s, v = 330 m/s

$n_0 = 1200$ Hz

To find the frequency of sound detected by the target we have to used Eq. (8.25)

$$n = n_0\left[\frac{v}{v - v_s}\right]$$

$$n = 1200\left[\frac{330}{330 - 220}\right]$$

$$n = 3600 \text{ Hz}$$

The frequency of sound detected by the target = 3600 Hz.

When echo is heard by rocket's detector, target is considered as source

$\therefore v_s = 0$

The frequency of sound emitted by the source (i.e. target) is n_0 = 3600 Hz, and the frequency detected by rocket is n'. Now listener is approaching the source and so we have to use.

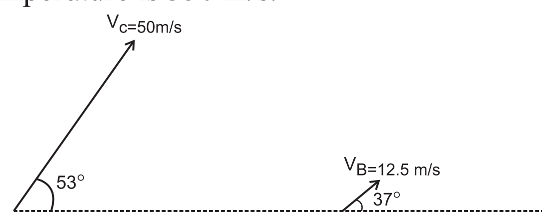
$$n' = n\left[\frac{v + v_L}{v}\right]$$

$$n = 3600\left[\frac{330 + 220}{330}\right]$$

$$n = 6000 \text{ Hz}$$

The frequency of echo detected by rocket = 6000 Hz

Example 8.7: A bat, flying at velocity V_B = 12.5 m/s, is followed by a car running at velocity V_C = 50 m/s. Actual directions of the velocities of the car and the bat are as shown in the figure below, both being in the same horizontal plane (the plane of the figure). To detect the car, the bat radiates ultrasonic waves of frequency 36 kHz. Speed of sound at surrounding temperature is 350 m/s.



There is an ultrasonic frequency detector fitted in the car. Calculate the frequency recorded by this detector.

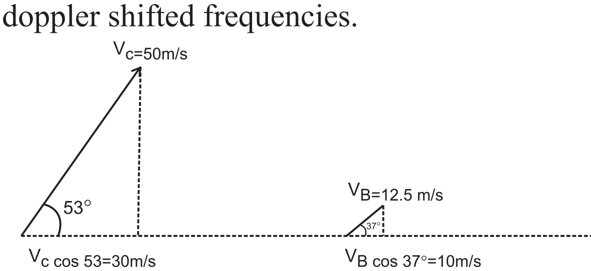
The ultrasonic waves radiated by the bat are reflected by the car. The bat detects these waves and from the detected frequency, it knows about the speed of the car. Calculate the frequency of the reflected waves as detected by the bat. (sin 37° = cos 53° ≈ 0.6, sin 53° = cos 37° ≈ 0.8)

Solution: As shown in the figure below, the components of velocities of the bat and the car, along the line joining them, are

$V_C \cos 53^0 \cong 50 \times 0.6 = 30 \text{ m s}^{-1}$ and

$V_B \cos 37^0 \cong 12.5 \times 0.8 = 10 \text{ m s}^{-1}$.

These should be used while calculating the doppler shifted frequencies.



Doppler shifted frequency, $n = n_0\left(\frac{v \pm v_L}{v \mp v_s}\right)$; upper signs to be used during approach, lower signs during recede.

Part I: Frequency radiated by the bat n_0 = 36 $\times 10^3$ Hz, Frequency detected by the detector in the car = n = ?

In this case, bat is the source which is moving away from the car (receding) while the detector in the car is the listener, who is approaching the source (bat). $v_s = V_B \cos 37^0 = 10$ m/s and

$v_L = V_C \cos 53^0 = 30$ m/s

The source (bat) is receding, while the listener (car) is approaching $\therefore n = n_0\left(\frac{v + v_L}{v + v_s}\right)$

$$\therefore n = 36 \times 10^3 \left(\frac{350 + 30}{350 + 10}\right)$$

$$= 38 \times 10^3 \text{ Hz} = 38 \text{ kHz}$$

Part II: Reflected frequency, as detected by the bat: Frequency reflected by the car is the Doppler shifted frequency as detected at the car. Thus, this time, the car is the source with emitted frequency $n_0 = 38 \times 10^3$ Hz, $n = ?$

Car, the source, is approaching the listener (bat).

Thus, $v_S = v_C \cos 53^0 = 30$ m/s

Thus, $v_L = v_B \cos 37^0 = 10$ m/s

Now bat-the listener is receding while car the source is approaching $\therefore n = n_0\left(\frac{v - v_L}{v - v_s}\right)$

$$\therefore n = 38 \times 10^3 \left(\frac{350 - 10}{350 - 30}\right)$$

$$= 38 \times 10^3 \times \frac{34}{32}$$

$$= 40.375 \times 10^3 \text{ Hz}$$

$$= 40.375 \text{ kHz}$$

Internet my friend

https://hyperphysics.phys-astr.gsu.edu/hbase/hframe.html

Exercises

1. Choose the correct alternatives

i) A sound carried by air from a sitar to a listener is a wave of following type.
   (A) Longitudinal stationary
   (B)Transverse progressive
   (C) Transverse stationary
   (D) Longitudinal progressive

ii) When sound waves travel from air to water, which of these remains constant ?
   (A) Velocity (B) Frequency
   (C) Wavelength (D) All of above

iii) The Laplace's correction in the expression for velocity of sound given by Newton is needed because sound waves
   (A) are longitudinal
   (B) propagate isothermally
   (C) propagate adiabatically
   (D) are of long wavelength

iv) Speed of sound is maximum in
   (A) air (B) water
   (C) vacuum (D) solid

v) The walls of the hall built for music concerns should
   (A) amplify sound (B) reflect sound
   (C) transmit sound (D) absorb sound

2. Answer briefly.

i) Wave motion is doubly periodic. Explain.
ii) What is Doppler effect?
iii) Describe a transverse wave.
iv) Define a longitudinal wave.
v) State Newton's formula for velocity of sound.
vi) What is the effect of pressure on velocity of sound?
vii) What is the effect of humidity of air on velocity of sound?
viii) What do you mean by an echo?
ix) State any two applications of acoustics.
x) Define amplitude and wavelength of a wave.
xi) Draw a wave and indicate points which are (i) in phase (ii) out of phase (iii) have a phase difference of $\pi/2$.

xii) Define the relation between velocity, wavelength and frequency of wave.

xiii) State and explain principle of superposition of waves.

xiv) State the expression for apparent frequency when source of sound and listener are

i) moving towards each other

ii) moving away from each other

xv) State the expression for apparent frequency when source is stationary and listener is

1) moving towards the source

2) moving away from the source

xvi) State the expression for apparent frequency when listener is stationary and source is.

i) moving towards the listener

ii) moving away from the listener

xvii) Explain what is meant by phase of a wave.

xviii) Define progressive wave. State any four properties.

xix) Distinguish between traverse waves and longitudinal waves.

xx) Explain Newtons formula for velocity of sound. What is its limitation?

3. Solve the following problems.

i) A certain sound wave in air has a speed 340 m/s and wavelength 1.7 m for this wave, calculate

a) the frequency b) the period.

[Ans a) 200 Hz, b) 0.005s]

ii) A tuning fork of frequency 170 Hz produces sound waves of wavelength 2 m. Calculate speed of sound.

[Ans: 340 m/s]

iii) An echo-sounder in a fishing boat receives an echo from a shoal of fish 0.45 s after it was sent. If the speed of sound in water is 1500 m/s, how deep is the shoal?

[Ans : 337.5 m]

iv) A girl stands 170 m away from a high wall and claps her hands at a steady rate so that each clap coincides with the echo of the one before.

a) If she makes 60 claps in 1 minute, what value should be the speed of sound in air?

b) Now, she moves to another location and finds that she should now make 45 claps in 1 minute to coincide with successive echoes. Calculate her distance for the new position from the wall.

[Ans: a) 340 m/s b) 255 m]

v) Sound wave A has period 0.015 s, sound wave B has period 0.025. Which sound has greater frequency?

[Ans : A]

vii) At what temperature will the speed of sound in air be 1.75 times its speed at N.T.P?

[Ans: 836.06 K = 563.06 °C]

viii) A man standing between 2 parallel eliffs fires a gun. He hearns two echos one after 3 seconds and other after 5 seconds. The separation between the two cliffs is 1360 m, what is the speed of sound?

[Ans:340m/s]

ix) If the velocity of sound in air at a given place on two different days of a given week are in the ratio of 1:1.1. Assuming the temperatures on the two days to be same what quantitative conclusion can your draw about the condition on the two days?

[Ans: Air is moist on one day and $\rho_{dry} = 1.1^2 \rho_{dry} = 1.21\ \rho_{moist}$]

x) A police car travels towards a stationary observer at a speed of 15 m/s. The siren on the car emits a sound of frequency 250 Hz. Calculate the recorded frequency. The speed of sound is 340 m/s.

[Ans : 261.54 Hz]

xi) The sound emitted from the siren of an ambulance has frequency of 1500 Hz. The speed of sound is 340 m/s. Calculate the difference in frequencies heard by a stationary observer if the ambulance initially travels towards and then away from the observer at a speed of 30 m/s.

[Ans : 266.79 Hz]

***